them? Robotic spacecraft offer an alternative to human spaceflight and can more easily be built to endure in the harsh environment of space.

57. What will the Cassini robot do?

The Cassini spacecraft will make a 4-year scientific tour of the Saturn system. The Cassini orbiter will conduct long-term, detailed, close-up studies of Saturn, its rings, its moons, and its space environment. Cassini is the best-equipped spacecraft we have ever sent to another world. The Cassini orbiter carries six instruments to "see" in four kinds of light (visible, infrared, ultraviolet, and radio). There are also instruments for detecting dust particles, magnetic fields, and charged particles such as protons and electrons.

The Cassini orbiter will release the Huygens probe, which will parachute through Titan's hazy atmosphere to the surface. The Huygens probe will carry a suite of instruments to measure various properties of Titan's atmosphere and surface. One of the probe's instruments will make more than 1,000 images of Titan's surface and clouds — sights never before seen by human beings!

58. What spacecraft have been to Saturn? How have we gathered information about Saturn up until now?

Saturn was first visited by Pioneer 11 in 1979 and later by Voyager 1 in 1980 and Voyager 2 in 1981. These spacecraft passed through the Saturn system and made many extraordinary observations and discoveries. Scientists have also used the Hubble Space Telescope (HST), which NASA placed in orbit around Earth in 1990, to study Saturn. HST has observed storms in Saturn's atmosphere and detailed structure in its rings. Using infrared cameras, HST has also detected large bright and dark regions deep beneath Titan's veil of haze. Scientists don't know yet what these features are — perhaps continents and ethane oceans?

There are many aspects of Saturn that cannot be studied or detected by remote sensing techniques such as using a telescope. For example, only a spacecraft flying within the Saturn system can directly sense Saturn's magnetic field. Also, only from a spacecraft beyond Saturn can we look back at the night side of Saturn (or its moons) to collect data on such things as nighttime temperatures or how much sunlight is blocked by the dust in Saturn's rings.

59. What will Cassini learn that we do not already know from Voyager and Hubble Space Telescope data?

The Pioneer 11 and Voyager flybys were an initial reconnaissance of Saturn. The Hubble Space Telescope (HST) has been used to detect possible continents or other large features on Titan's surface. Cassini is a follow-on to these missions, but instruments on the Cassini orbiter are capable of much more detailed observations of the planet, moons, and rings than either Voyager or HST. The Cassini spacecraft will also have 4 years to study the Saturn system instead of a few days as with a flyby mission like Voyager or a few hours every few months as with HST.

In addition, the Huygens probe will parachute into Titan's atmosphere to the surface, and instruments on the probe will observe detailed properties of an atmosphere and surface that Voyager and Hubble could never have seen. Cassini's scientific objectives cannot be completed by HST because of HST's huge distance from Saturn and the very different instruments that HST and Cassini carry.

60. Why care about the Cassini mission?

The Cassini spacecraft is a robotic ambassador for all of humanity. It is an extension of our senses to a distant, magnificent world full of mysteries. Solving some of these mysteries has the power to teach us about ourselves and our place in the Universe. The Cassini mission is an expression of our deep desire to learn — to cross the boundary between the known and unknown. Thanks to the world's myriad possibilities for communicating what Cassini is doing, through the Internet, newspapers, television, radio, and classrooms, it is possible for all of us to share in this extraordinary adventure! How exciting it will be at last to unveil some of the mysteries of Saturn and Titan — and certainly create just as many new mysteries as well.

61. Why is NASA's mission to Saturn called Cassini?

The Cassini spacecraft is named after the Italian–French astronomer Jean-Dominique Cassini (or Giovanni [Gian] Domenico Cassini), who figured prominently in the earliest discoveries about the Saturn system. The astronomer Cassini made his observations of Saturn from the Paris Observatory in the late 17th century. He used a series of increasingly larger telescopes to discover four of Saturn's major moons: Iapetus, Rhea, Tethys, and Dione. In 1675, Cassini discovered that Saturn's ring was split into two parts by a division about 4,600 km (2,900 mi) wide. The gap between the two parts of the ring would become known as the Cassini Division, and the rings were given separate names.

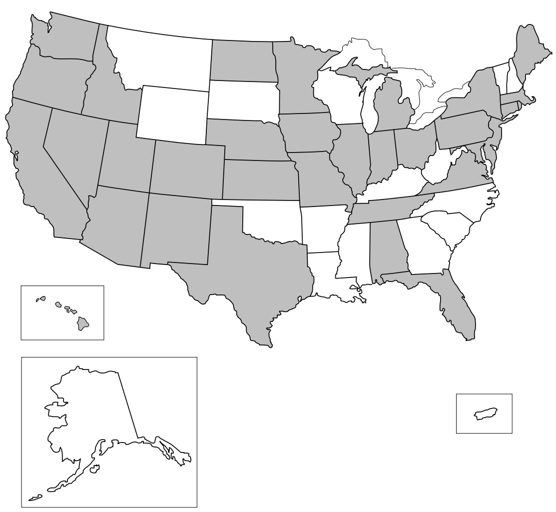
62. How much does the Cassini mission cost? Who pays for it?

The total cost for the Cassini mission is about $3.2 billion. This includes the Cassini orbiter, the Huygens probe, the Titan IV launch vehicle, and the United States' portion of mission operations and data analysis.

NASA projects are funded by the U.S. government, and thus much of Cassini is paid for by the taxpayers of the United States. The Cassini mission involves extensive international collaboration. The Huygens probe, the high-gain antenna on the Cassini orbiter, and portions of three science instruments were built in Europe, and were paid for by the people of Europe. We all have a vested interest in the success of the Cassini mission!

63. How long does it take to plan and carry out a mission like Cassini?

About 5 to 8 years are required from approval to launch for a sophisticated mission like Cassini. For example, Voyager 2 was approved in May 1972 and launched in August 1977. Cassini was approved in October 1989 and launched in October 1997. Cassini is the last of NASA's series of giant missions to the outer



Areas shown in gray represent the states and countries participating in the Cassini–Huygens mission.

planets of our Solar System. Smaller spacecraft are being developed and launched in 2 to 3 years. In the case of Cassini, the mission is designed to last at least 11 years after the launch: 7 years traveling to Saturn, and 4 years investigating the Saturn system.

Planning and carrying out a mission like Cassini requires several phases, which are named as follows: Phase A, Concept Study; Phase B, Definition and Preliminary Design; Phase C, Detailed Design; Phase D, Development through Launch and Instrument Checkout; and Phase E, Mission Operations and Data Analysis.

NASA defines the end of a spacecraft mission according to a specific plan, but this doesn't mean the spacecraft won't outlive that plan. For example, although the grand scientific tours of Voyager 1 and 2 are complete, flight controllers are still in touch with the two Voyager spacecraft as they hurtle away from the Solar System toward interstellar space. Astronomers hope that the Voyagers will eventually return data about the heliopause, which is the boundary between the region of space influenced by our Sun and the region of space influenced by other stars.

The Spacecraft

64. How big is the Cassini spacecraft?

Height and Width: Cassini is the largest interplanetary spacecraft ever built by the United States. It is about the size of a school bus. The spacecraft is about two stories tall (6.8 m, or 22 ft), and 4 m (13 ft) across. It would take about 7 large adults with arms outstretched to encircle Cassini.

Mass and Weight: The mass of the Cassini spacecraft is 5,650 kg, which includes the Huygens probe (370 kg), the Cassini orbiter's science instruments (370 kg) and 3,130 kg of propellant. Before launch, more than half of Cassini's weight was rocket propellant! At the surface of Earth, the Cassini spacecraft would weigh about 12,400 pounds, or approximately 6 tons. That's about the weight of three or four medium-sized cars!

Cassini–Huygens in High Bay 2 at the Jet Propulsion Laboratory.

65. How much wire is used in the Cassini spacecraft?

Engineers estimate that Cassini uses approximately 12 km (7.5 mi) of wiring to interconnect its electrical components.

66. Is the Cassini spacecraft really all covered with gold?

Much of Cassini is covered with gold-colored material, but it's not really gold. It's a multilayer fabric attached to the spacecraft like clothing to protect it from extremes of hot and cold and from impacts by small space rocks and dust in space called micrometeoroids. The fabric looks gold because the top layer is a translucent amber material called KAPTON®, which has a coating of shiny aluminum. Together, they look like shiny gold foil.

In addition, a large portion of Cassini's protective layers are graphite-filled blanketing. This black covering protects Cassini's science instruments without interfering with their operations. For example, gold blanketing near one of Cassini's cameras might cause unwanted reflections to appear in the images it makes.

Cassini–Huygens in the test chamber at the Jet Propulsion Laboratory.

67. Will the spacecraft use solar panels to provide power to the instruments on Cassini?

No. Cassini uses radioisotope thermoelectric generators, or RTGs. To identify the most appropriate power source to run Cassini's instruments, radios, and computers, NASA's Jet Propulsion Laboratory conducted an in-depth analysis of the available electrical power systems, including systems that use solar energy. Cassini's instruments, radios, and computers require 600 to 700 watts. For comparison, the power demand for an average American residential home is about 1,400 watts. The challenge for Cassini's designers was that this power must be produced reliably for many years at a distance that is 9.6 times farther from the Sun than Earth is. This power must also be supplied while keeping the spacecraft small enough and light enough to be launched from Earth.

If the Cassini spacecraft were equipped with the highest efficiency solar cells available, such as those developed by the European Space Agency, it would make the spacecraft too heavy for launch to Saturn. The resulting solar arrays would cover an area larger than two tennis courts! RTGs are thus the only feasible power system for the Cassini–Huygens mission.

The RTGs start the mission providing about 820 watts of power, and end the mission providing about 650 watts. The power output declines because RTGs generate energy from a radioactive substance called plutonium that decays over time. It is important to know that Cassini's three RTGs have nothing to do with the launch or propulsion of the spacecraft.

68. How does an RTG work? If it involves plutonium, is it dangerous?

An RTG uses the heat energy from a radioactive source, plutonium (Pu-238). The radioactivity generates heat, which in turn is converted to electrical energy that powers Cassini's instruments, radios, and computers.

Although plutonium is indeed a very toxic substance if breathed into the lungs, Cassini's RTGs contain a heat-resistant, ceramic form of it called plutonium dioxide. These ceramic modules are designed and packaged to prevent the formation of fine dust particles of plutonium that would be harmful if breathed into the lungs. Years of extensive safety testing and analyses have demonstrated that RTGs are extremely rugged and resistant to a release of the plutonium dioxide fuel, even in severe accident environments. In October 1968, an Atlas rocket carrying an RTG was destroyed shortly after launch from Vandenberg Air Force Base. The plutonium-containing portions of the RTG fell into the ocean intact, and all the plutonium was recovered and reused in a subsequent mission.

69. How well can Cassini aim its instruments?

Some of Cassini's instruments must be aimed precisely to gather data. They do not swivel by themselves but require the entire spacecraft to point in the desired direction. The spacecraft can point the instruments with an accuracy of about 0.06° (1/17th of a degree). Once pointed, the Cassini spacecraft is extremely stable.

The Science Instruments

70. What kinds of instruments does the Cassini orbiter have? What do they do?

In some ways, the Cassini spacecraft has senses better than our own. For example, Cassini can "see" in wavelengths of light and energy that the human eye cannot. (See the *Appendices* for an illustration of the electromagnetic spectrum.) The instruments can "feel" things about magnetic fields and tiny dust particles that no human hand could detect. The Cassini spacecraft has been designed with 18 major science instrument packages: 12 on the Cassini orbiter, and six on the Huygens probe.

Even without knowing the details of all of the instruments and the nature of what they are measuring or detecting, it is still possible to discern several things about them from their descriptions. For example, you can classify the science instruments in a way that enables you to make a comparison with the way your own senses operate. Your eyes and ears are "remote sensing" devices because you can receive information from remote objects without being in direct contact with them. Your senses of touch and taste are "direct sensing" devices. Your nose can be construed as either a remote or direct sensing device. You can certainly smell the apple pie across the room without having your nose in direct contact with it, but the molecules carrying the scent do have to make direct contact with your sinuses. The Cassini instruments are:

1. Imaging Science Subsystem (ISS)
Makes images in visible light, and some infrared and ultraviolet light. The ISS has a camera that can take a broad, wide-angle picture and a camera that can record small areas in fine detail. Engineers anticipate that ISS will return hundreds of thousands of images of Saturn and its rings and moons! [Remote sensing / sight]

2. Radio Detection and Ranging (RADAR)
Produces maps of Titan's surface and measures the height of surface objects (like mountains and canyons) by bouncing radio signals off of Titan's surface and timing their return. This is similar to listening for the echo of your voice across a canyon to tell how wide the canyon is. Radio waves can penetrate the thick veil of haze surrounding Titan. In addition to bouncing radio waves, the RADAR instrument will listen for radio waves that Saturn or its moons may be producing. [Remote active sensing / listening to echo; Remote passive sensing / sight]

3. Radio Science Subsystem (RSS)
Uses radio antennas on Earth to observe the way radio signals from the spacecraft change as they are sent through objects, such as Titan's atmosphere or Saturn's rings. RSS uses radio receivers and transmitters at three different wavelengths. This gives detailed information on the structure of the rings and atmosphere. [Remote sensing / sight or hearing]

4. Ion and Neutral Mass Spectrometer (INMS)
Analyzes charged particles (like protons and heavier ions) and neutral particles (like atoms) near Titan and Saturn to learn more about their atmospheres. [Direct and remote sensing / smell]

5. Visible and Infrared Mapping Spectrometer (VIMS)
Makes pictures using visible and infrared light to learn more about the composition of moon surfaces, the rings, and the atmospheres of Saturn and Titan. VIMS also observes the sunlight and starlight that passes through the rings to learn more about ring structure. [Remote sensing / sight]

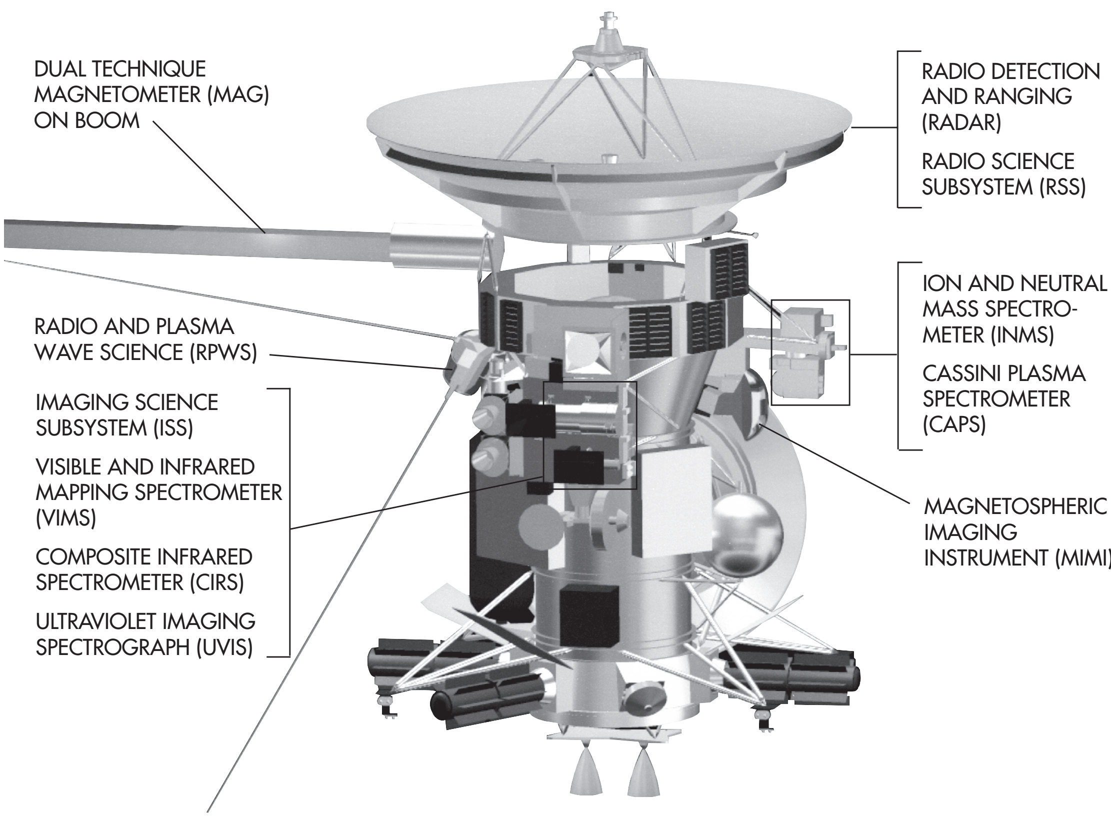
6. Composite Infrared Spectrometer (CIRS)
Measures the infrared light coming from an object (such as an atmosphere or moon surface) to learn more about its temperature and what it's made of. [Remote sensing / sight]

7. Cosmic Dust Analyzer (CDA)
Senses the size, speed, and direction of tiny dust grains near Saturn. Some of these particles are orbiting Saturn, while others may come from other solar systems. [Direct sensing / touch or taste]

8. Radio and Plasma Wave Science (RPWS)
Receives and measures the radio signals coming from Saturn, including the radio waves given off by the interaction of the solar wind with Saturn and Titan. [Direct & remote sensing / many senses]

9. Cassini Plasma Spectrometer (CAPS)
Measures the energy and electrical charge of particles such as electrons and protons that the instrument encounters. [Direct sensing / touch, taste, smell]

10. Ultraviolet Imaging Spectrograph (UVIS)
Makes images of the ultraviolet light reflected off an object, such as the clouds of Saturn and/or its rings, to learn more about their structure and composition. [Remote sensing / sight]



The Cassini–Huygens spacecraft.

11. Magnetospheric Imaging Instrument (MIMI)
Produces images and other data about the particles trapped in Saturn's huge magnetic field, or magnetosphere. [Direct and remote sensing / sight and smell]

12. Dual Technique Magnetometer (MAG)
Measures the strength and direction of the magnetic field around Saturn. The magnetic fields are generated partly by the intensely hot molten core at Saturn's center. Measuring the magnetic field is one of the ways to probe the core, even though it is far too hot and deep to actually visit. [Direct and remote sensing / touch and smell]

71. How well can the Cassini cameras see?

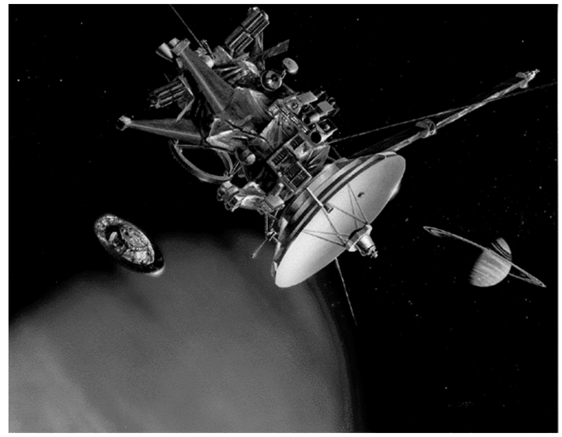
Cassini's highest-resolution camera is able to see a penny, 1.5 cm (0.5 in) across, from a distance of nearly 4 km (2.5 mi).

72. How do we know what color a planet or moon really is?

In several of Cassini's cameras, color filters can be placed in and out of the cameras so that the detector sees only one color at a time. Each image is then transmitted to Earth. Image processing computers on Earth combine the data to recreate the image in its original colors. Our eyes work in a similar way: we can really see images just in three primary colors — red, green, and blue. Our brains combine these three colors to make other colors, such as purple, yellow, and orange.

73. What does the Huygens probe do?

Soon after arriving in the Saturn system, the Cassini orbiter will release the Huygens probe, which will descend into the atmosphere of Titan — Saturn's largest moon. The Huygens probe, built by the European Space Agency, carries six instruments to collect data on Titan's clouds, atmosphere, and surface.



Rendition of the Huygens probe being released above Titan.

The 320 kg probe is built a little bit like a clam: it's hard on the outside, to protect the delicate instruments on the inside. The shell must be built so it can survive the 20,000 km/hr (13,000 mi/hr) rush when it first hits the atmosphere, and the 12,000 °C (22,000 °F) temperatures as the friction from Titan's atmosphere violently slows it down.

As the 2.7 m (8.9 ft) diameter probe enters Titan's atmosphere, it will begin taking measurements in the haze layer above the cloud tops. During its 2.5-hour descent — first on a main parachute and later on a smaller "drogue" parachute — various instruments will measure the temperature, pressure, density, and composition of the atmosphere. As the Huygens probe finally breaks through the bottom layer of clouds, a camera with 11 simultaneous viewing directions will capture panoramic images of Titan's surface.

The probe's instruments will also measure properties of Titan's surface as it descends and possibly after landing — if the probe survives the impact with the surface. The probe lands relatively hard, at about 25 km/hr (15 mi/hr) and thus may not survive the landing.

APPENDIX 1

74. What kinds of instruments does the Huygens probe have?

The Huygens probe carries six instruments. As the probe falls through the atmosphere toward Titan's surface, some of the instruments will be busily monitoring the atmosphere by looking out windows in the probe or "sniffing" the atmosphere through holes. Other instruments will start working after the probe lands — or floats — on Titan. Radios on the probe will send back data to the Cassini orbiter. These are the instruments on the Huygens probe:

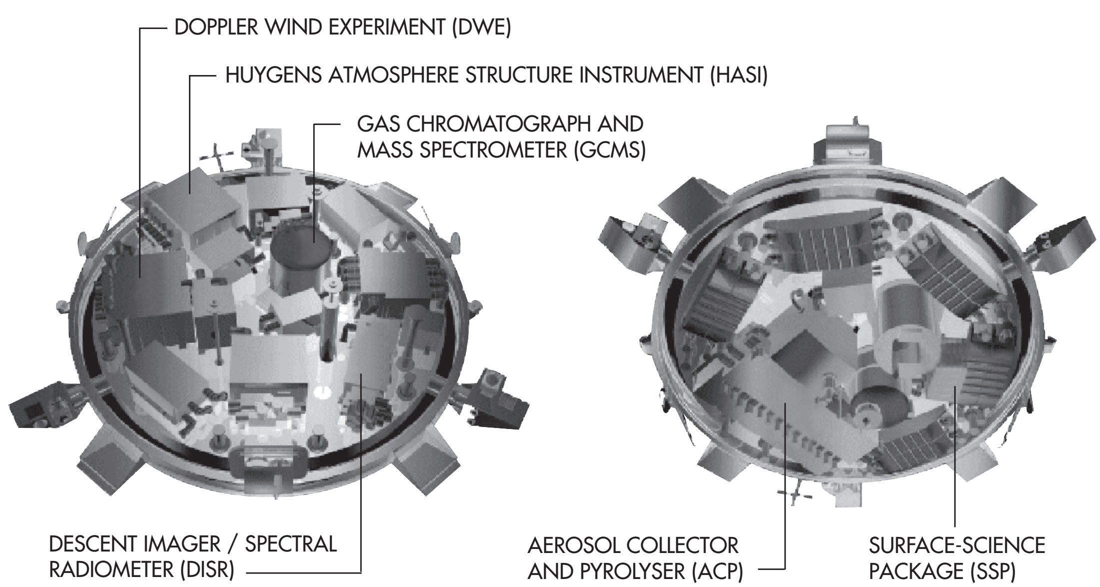
1. Gas Chromatograph and Mass Spectrometer (GCMS)
Analyzes the amounts of various gases in Titan's atmosphere. It will look for organic molecules that may indicate interesting chemistry happening in Titan's atmosphere, as well as simpler molecules that will help scientists understand how Titan formed. [Direct sensing / smell]

2. Aerosol Collector and Pyrolyser (ACP)
Detects the particles in Titan's thick, hazy clouds. The ACP might help detect the gases and clouds that would be spewed by any active volcanoes on Titan. [Direct sensing / smell]

3. Descent Imager / Spectral Radiometer (DISR)
Takes pictures of Titan as the probe descends toward the surface. It also measures how Titan's clouds dim the Sun's light. This will help astronomers understand how Titan is heated by the Sun. [Remote sensing / sight]

4. Huygens Atmosphere Structure Instrument (HASI)
Watches for lightning and listens for thunder in Titan's clouds. Using the probe's batteries for power, HASI will also create its own very tiny lightning bolts to explore how Titan's atmosphere interacts with electricity. [Remote sensing / sight, hearing; direct sensing / touch]

5. Doppler Wind Experiment (DWE)
Measures the speeds of Titan's winds. Does Titan have huge hurricanes, or is it a relatively calm place? Maybe, like Earth, it's windy at some altitudes and more calm at others. This instrument is so sensitive that it might also measure the probe gently swinging below its parachute! [Direct sensing / touch, balance]



Instruments on the two sides of the Huygens probe.

6. Surface-Science Package (SSP)
This set of eight instruments examines the probe's landing site — whether rocks, snow, "goo," or a lake. The SSP has detectors to measure how hard the probe hits, the temperature, the speed of sound in Titan's atmosphere, and the type of liquid in which the probe may be floating. [Direct sensing / touch, hearing, taste]

75. What happens to the Huygens probe after it lands on Titan?

The Huygens probe may survive landing on solid ground, ice, or even liquid. Engineers designed it to float! Many scientists theorize that Titan may be covered by lakes or oceans of methane or ethane, so the Huygens probe is designed to function whether it goes "splash" or "splat." One instrument on board will tell us if Huygens is bobbing in liquid, and other instruments on board will tell us what that liquid is made of. If the battery-powered probe survives its landing, it will send measurements from Titan's surface until its batteries die or the Cassini orbiter flies out of radio contact — for up to 30 minutes.

After the probe runs out of battery power, it could sit wherever it lands for thousands of years. It could be caught in a landslide or an avalanche, if such phenomena occur on Titan! Huygens could wash up on some frigid Titanic beach. Or, it could land on a methane iceberg and float endlessly on an ethane sea. Wherever it lands, organic chemical compounds falling from Titan's sky will likely rain down on it. Like a car parked outdoors in Los Angeles for too long, Huygens eventually would be coated with the residue of this light brown, smog-like goo. Maybe in the far future, we will return to Titan to find out what became of the Huygens probe.

76. If the Huygens probe were to sink, would there be any way to send information back?

No. If the probe were to sink in cold liquid ethane, which may well be present on Titan, the batteries and radio would not operate well, and the probe would not be able send information back to the Cassini orbiter.

The People of the Cassini Team

77. How many people have worked on Cassini?

At its peak, Cassini's development involved about 4,500 people, including 3,000 in the U.S. and 1,500 in European countries. This includes engineers, scientists, and many other people at universities, research institutions, and in industry. These people worked in 32 U.S. states and 16 European countries.

A life-size model of Cassini–Huygens at JPL, with a few of the thousands of Cassini team members.

Another way of expressing the magnitude of the human effort involved is to consider the number of workyears needed to prepare Cassini for launch. One workyear is equivalent to 1 person working full-time for 1 year. Preparing the Cassini mission for launch took about 13,000 workyears of effort — almost half of what it must have taken to build the Great Pyramid of Cheops at Giza!

78. Who manages the Cassini Project?

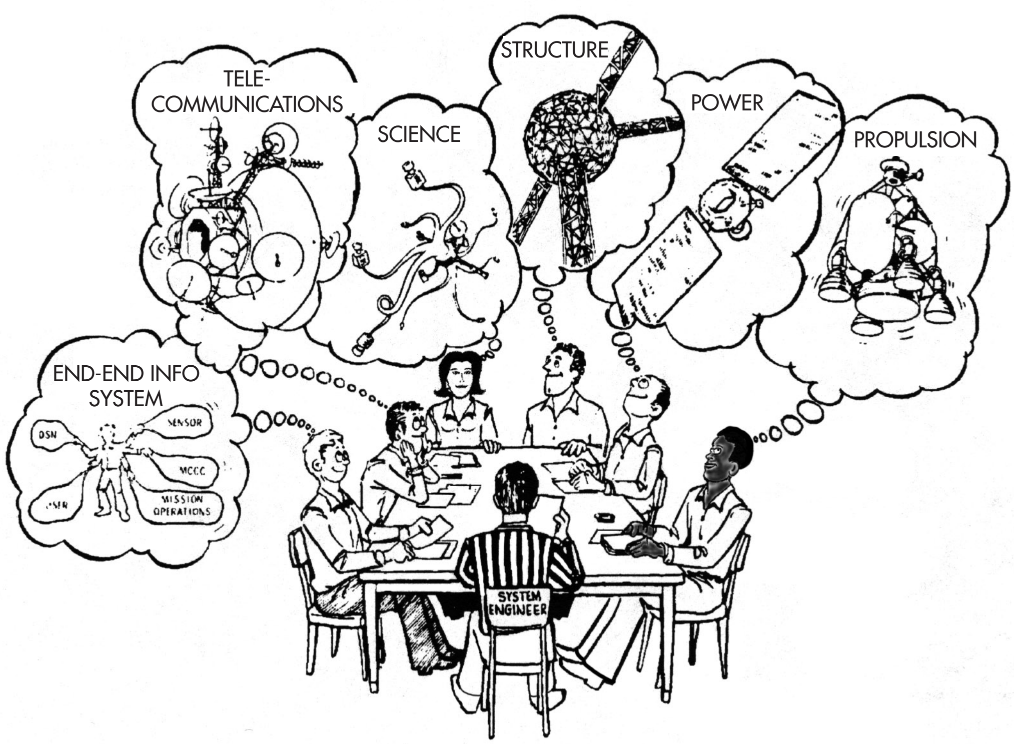
The Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology, manages the Cassini Project. JPL is under contract with NASA to design and fly robotic space missions. JPL is especially famous for its work in planetary science, including the Voyager missions to the outer planets and Pathfinder to Mars.

79. What sorts of people work on a space project like Cassini?

It is a monumental task to design, build, launch, and fly a sophisticated robot like Cassini. A great diversity of talented people are required to make it happen. Most of those who work on the Cassini project are scientists and engineers, but the project also involves people such as computer programmers, educators, machinists, electricians, secretaries, security guards, and travel agents.

80. How could I prepare for a career involving a space project?

In preparation for careers involving a space project, it is wise to take all the courses you can in school, especially math, science, and English courses. Go to college if possible, and pick a field of study that particularly interests you. Science and engineering are the most likely pathways to becoming involved in a space exploration project, but there are other ways as well. Seek out someone who is already in a space-related career and talk to them about what skills and attitudes they needed to be successful. It is helpful to become aware of, and begin to cultivate, some of the useful job skills that may not necessarily be taught in school. In addition to having basic mathematical skills and some sort of technical training, it is helpful to be enthusiastic, creative, able to learn new things, speak and write well, use a computer, work well in a team, and persevere through problems.



APPENDIX 1

Launch and Navigation

81. When was Cassini launched?

Cassini was scheduled to be launched on 6 October 1997. Several weeks before launch, engineers detected a minor problem with insulation inside the Huygens probe, and program managers rescheduled the launch for 13 October 1997. After the launch was postponed once more due to technical problems, Cassini was sent on its journey to Saturn at 4:43 in the morning on 15 October 1997, from Cape Canaveral, Florida.

82. Which launch vehicle did Cassini use?

A Titan IV rocket launched Cassini on its way to Saturn. Cassini has a mass of 5,650 kg, and thus it takes a mighty force to free the spacecraft from Earth's gravity. The Titan IV is the most powerful expendable launch vehicle in the US fleet. It was built by Martin Marietta — now Lockheed Martin — under contract to the U.S. Air Force.

The Titan IV did not send Cassini by itself. Rather, the Titan launched both Cassini and an upper stage rocket called a Centaur. The Centaur helped to place Cassini into a temporary orbit around Earth called a parking orbit. From there, the Centaur waited until Cassini was in the right position, and then fired its engines to propel Cassini away from Earth and toward Venus for Cassini's first gravity assist. After firing its engines, the Centaur disconnected from Cassini and the spacecraft began its long, unpowered coast through space. The Centaur was developed by General Dynamics and is the most powerful upper stage in the world.

The Titan IV launch vehicle, including the Centaur, has a mass of 4.4 million kilograms, of which about 90%, or 4 million kilograms, is fuel! The 370 kilograms of Cassini's scientific instruments seems amazingly tiny next to the mass of the launch vehicle.

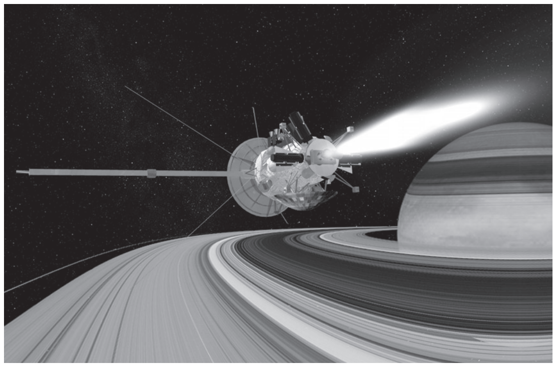
The Titan IV vehicle launching Cassini.

83. How much rocket fuel does Cassini carry in order to complete its mission at Saturn?

Cassini carries about 3,000 kilograms of fuel (or propellant). Some of the fuel will be used to direct the spacecraft's course on its way to Saturn, some will be used to slow down the spacecraft as it arrives at Saturn, and some will be used while touring the Saturn system. Well over 99% of Cassini's trip, however, will be an unpowered coast through space.

84. When does Cassini arrive at Saturn?

Cassini is due to arrive at Saturn on 1 July 2004. Just before Cassini's closest approach to Saturn, the spacecraft fires its engines for over an hour to slow itself down enough to be captured into orbit around Saturn. Cassini will be moving so fast — 32 km/sec (71,000 mi/hr) — that if it didn't fire its engines, it would cruise past Saturn and never return.



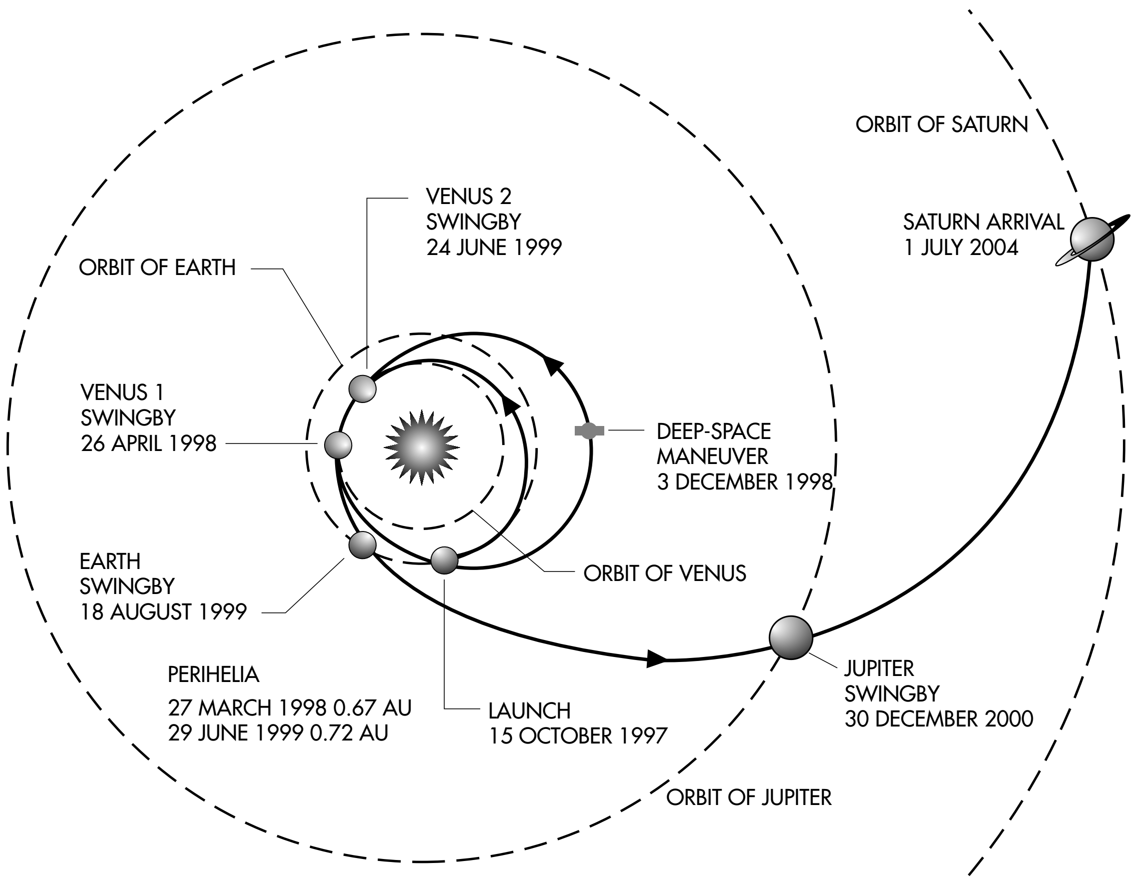
Artist's concept of Saturn orbit insertion.

85. How long does the Cassini mission last?

The Cassini mission is planned to last a total of 11 years: 7 years traveling from Earth to Saturn, and 4 years touring the Saturn system. However, the spacecraft could continue to send information back to Earth for many more years.

86. Why does it take so long to get to Saturn?

Cassini is an extremely heavy spacecraft — the heaviest interplanetary spacecraft ever launched by the United States. Because it is so heavy, it was not feasible to boost it to Saturn directly. Instead, the spacecraft was launched inward toward Venus, and has two Venus flybys, one Earth flyby, and one Jupiter flyby on the way to Saturn. Each of these flybys increases the speed of the spacecraft using a gravity assist. (This kind of flyby is sometimes called a swingby.) Cassini will eventually get to Saturn, but it takes time to speed up the spacecraft and get it going fast enough.



Cassini–Huygens' interplanetary trajectory.

87. Couldn't we get to Saturn faster if we flew directly to Saturn instead of wrapping around other planets?

Yes, but we would need a much more powerful launch vehicle or a much smaller spacecraft than Cassini. Given the launch technology and the mass of Cassini, using gravity assists from other planets is absolutely necessary to increase Cassini's speed. Without using gravity assists from other planets, or a larger launch vehicle, it just wouldn't be possible to get Cassini to Saturn at all, in any amount of time!

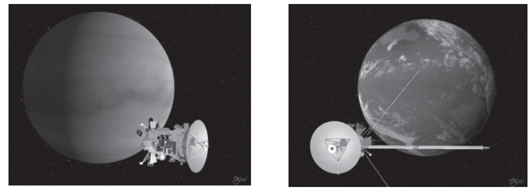
The increase in speed provided by the gravity assists from Venus, Earth, and Jupiter would otherwise require an additional 3.6 million kilograms of fuel. During Cassini's 4-year tour of Saturn, the 40 gravity assists from Titan will provide the equivalent of another 49 million kilograms of fuel. This is over 12 times as much fuel as the Titan IV launch vehicle carries!

88. What is gravity assist?

Gravity assist is a way of using the gravitational pull of a massive planet on a spacecraft in order to transfer momentum and energy from the planet to the spacecraft that is flying (or "swinging") by it. When the Voyager spacecraft flew by Jupiter, it gained 16 kilometers per second of speed relative to the Sun, at a cost of initially reducing Jupiter's orbital speed by about 30 cm (1 ft) per trillion years. Exploration of the outer planets would not be possible without gravity assist, unless we were to use smaller payloads and mightier rockets than currently exist. Cassini gained about 6 km/sec relative to the Sun at the first Venus swingby, 7 km/sec at the second Venus flyby, 6 km/sec at Earth, and will gain about 2 km/sec at Jupiter.

89. How close does Cassini come to Earth during its flyby?

Cassini flies about 1,170 km (720 miles) over Earth during its flyby on August 18, 1999 — higher than the Hubble Space Telescope's altitude of 600 km (370 miles). Cassini swings by Jupiter at a much greater distance of almost 10 million km (6 million mi).



Artist's concepts of the Venus flyby (left) and the Earth flyby (right).

90. Can we see the Cassini spacecraft from Earth during its flyby of Earth?

Yes, but at Cassini's closest approach to Earth, it travels very fast and is just about to pass into Earth's shadow. It would be visible for about 30 seconds as a moving point of light about as bright as stars of the Big Dipper. If you were at a location on Earth near Cassini's path, Cassini would come from the west at dusk and traverse about half the sky before passing into Earth's shadow. Cassini would emerge from Earth's shadow and reappear about 24 minutes later. At this point, Cassini would be much more distant from Earth and so would appear much dimmer, although you could still see it with binoculars if you knew where to look.

91. How far does Cassini travel from Earth to Saturn?

The direct distance from Earth to Saturn varies from about 1.2 billion km (750 million mi) to 1.6 billion km (980 million mi), depending on where Saturn and the Earth are on their laps around the Sun. Due to its flybys of Venus, Earth, and Jupiter, Cassini actually travels more than 3 billion km (2 billion mi) to reach Saturn. Once there, Cassini travels another 1.7 billion km (1.1 billion mi) on its tour of the Saturn system.

92. How fast does Cassini go?

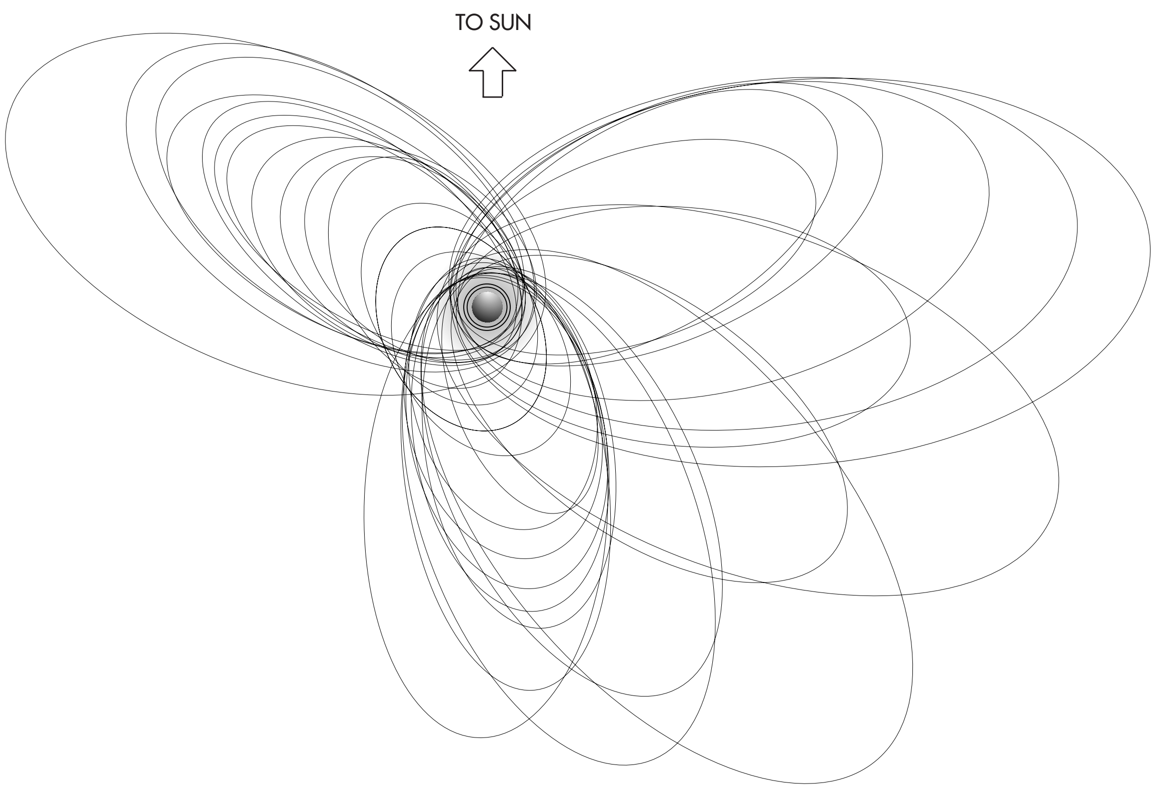
During the Cassini mission, the spacecraft reaches relative speeds of 13 km/sec (or about 29,000 mi/hr) flying by Venus (equivalent to flying from Los Angeles to Boston in under 5 minutes!), and 19 km/sec (43,000 mi/hr) flying by Earth. While cruising to Saturn, Cassini's speed is as high as 32 km/sec (71,000 mi/hr). At this speed, even the gravity of Saturn is not enough to capture it — Cassini must fire its engines to slow down at Saturn, or it would continue on past the planet and never return.

93. How close does Cassini fly to Saturn's cloudtops?

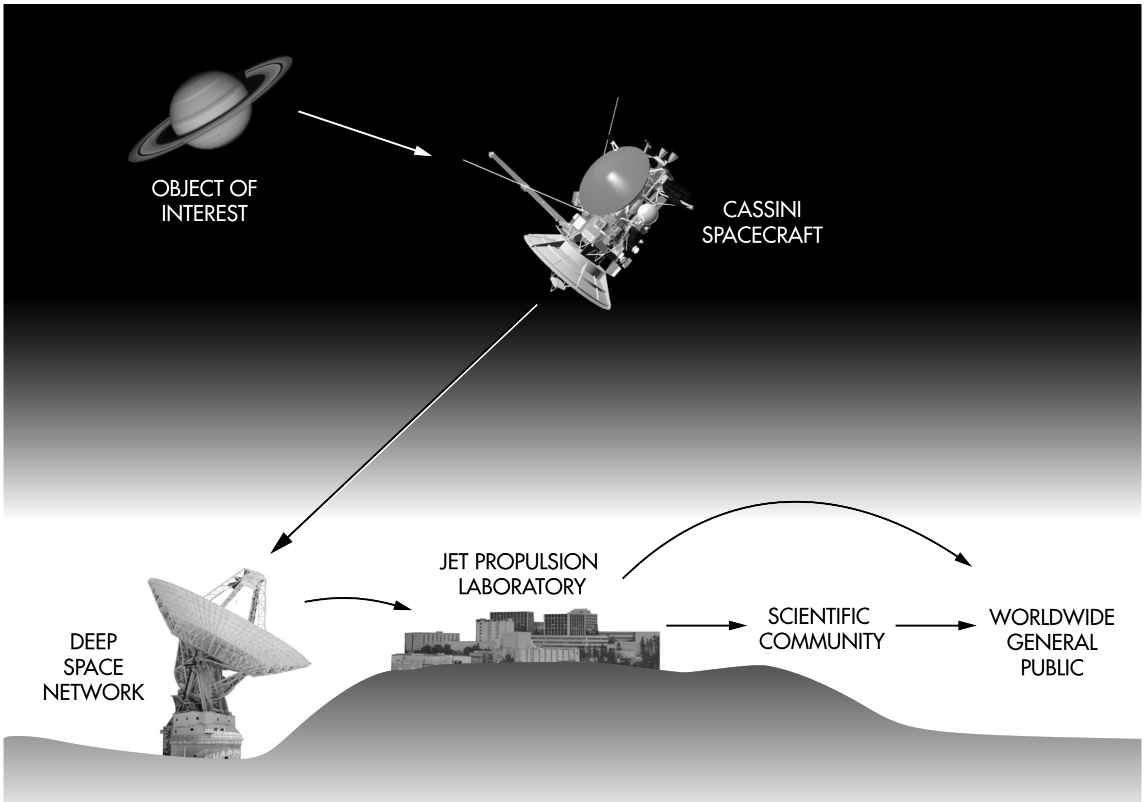
Upon reaching Saturn, Cassini swings close to the planet, to an altitude only one-sixth the diameter of Saturn itself — about 20,000 km (12,000 mi). This begins the first of more than 70 orbits during its 4-year mission, and it's the closest that Cassini ever gets to the planet.

94. What happens to Cassini after it completes the Saturn tour?

After completing its tour, the spacecraft will continue orbiting Saturn. If all goes well during the mission, there should be enough attitude-control propellant and electrical power for the spacecraft to continue to relay data back to Earth for many years (just as Magellan did and the two Voyagers still do). However, budget constraints may limit how long NASA is able to operate the spacecraft after the end of the mission in 2008. Cassini will continue to orbit Saturn until the spacecraft runs out of propellant. Before it runs out of propellant, flight controllers will probably place Cassini in an orbit that minimizes its chances of colliding with any of the moons for a long time.



A sample Saturn orbital tour. The view is from above Saturn's north pole. This type of diagram is called a petal plot because each orbit resembles the petal of a flower. The range of orbit orientations allows a detailed survey of Saturn's magnetosphere and atmosphere.



Data flow from Saturn to Cassini to Earth.

Communications and Science Data

95. How long does it take for a radio signal to travel between Earth and Saturn?

A signal takes between 70 and 90 minutes to reach Earth from Saturn. The exact time depends on the ever-changing locations of Earth and Saturn in their orbital laps around the Sun. Radio waves travel at the speed of light, or 300,000 km/sec (186,000 mi/sec).

96. Has anything been learned from the failure of the high-gain antenna on the Galileo spacecraft which has altered the design of Cassini's high-gain antenna?

The Galileo spacecraft's high-gain (or main) antenna was designed to unfurl itself like an umbrella while in flight to Jupiter. When flight controllers commanded it to open, it opened partially but not enough for it to be of use transmitting data between the spacecraft and the ground. The Cassini mission had already planned to use a fixed antenna before the failure of Galileo's folding antenna. The Cassini high-gain antenna, which was provided by the Italian Space Agency, has no moving parts. The failure of Galileo's antenna triggered an intense analysis of the Cassini spacecraft to avoid other types of mechanical failures.

97. How much power do Cassini's radio transmitters put out?

Cassini's radio transmitters send out about 20 watts of power — about the same amount of power it takes to operate a refrigerator's light bulb.

98. What is the Deep Space Network?

The Deep Space Network (DSN) is a collection of huge, dish-shaped radio antennas distributed around the world that send and receive messages to and from spacecraft like Cassini.

If you could place one of NASA's 70-m Deep Space Network antennas inside the Rose Bowl in Pasadena, California, it would look like this.

Cassini will regularly use the Deep Space Network's largest antennas, which are 70 m (230 ft) in diameter — nearly the size of a football field. The DSN's large radio dishes must be pointed to within a small fraction of a degree of a spacecraft's location to be able to communicate with it.

99. What if something goes wrong with the spacecraft? Do we have to wait an hour to learn about it?

Yes, we would have to wait to learn about a problem, but Cassini might be able to take care of itself in the meantime. Much planning has been done for times when things don't go as planned. Many of Cassini's parts have backups that can be activated from Earth, or in some cases turned on automatically by the spacecraft. For example, Cassini has two radio receivers. If one should fail, the spacecraft's computers would realize that they haven't heard from Earth recently, and automatically switch to the backup receiver to listen for further instructions. Cassini's capabilities for detecting and handling problems by itself are collectively called "fault protection."

100. How much science data will Cassini return?

On a busy day at Saturn, Cassini could transmit up to 500 megabytes (500,000,000 bytes, or about a CD-ROM's worth) of information to Earth. More than 300 gigabytes of science data will be sent back to Earth during the mission. This would fill more than 400 CD-ROMs — a stack of CDs that would be higher than 4 m (13 ft). It is also about the amount of information in 2,400 sets of the Encyclopedia Britannica.

101. How many pictures will be sent back from Cassini–Huygens?

Engineers estimate that the Cassini mission will return as many as a million images of Saturn, the rings, Titan, and the other moons. This includes more than a thousand images taken by the Huygens probe of scenes never before seen by humans.